AMOUNTS AND RELATIVE SIGNIFICANCE OF RUNOFF TYPES IN THE TRANSPORT OF NITROGEN INTO A STREAM DRAINING AN AGRICULTURAL WATERSHED

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Abstract. The concentration and amounts of NO_3–N and TN transported in surface, accelerated subsurface, and subsurface runoff and stream flow draining a 20 ha pasture watershed were measured over a period of 3 yr. A slight decrease and increase of NO_3–N and particulate N concentrations, respectively, were obtained with increased flow of the runoff types and stream, due to dilution and increased sediment transport, respectively. The concentration of NO_3–N in surface, accelerated subsurface and subsurface runoff and stream flow averaged for the 3 yr was 0.3, 6.6, 4.8, and 4.6 mg l^{-1}, respectively, amounting to 0.5, 9.4, 11.6, and 16.8 kg ha^{-1} yr^{-1}, respectively, transported annually. Although NO_3–N accounted for only a minor proportion of the TN transported in surface runoff (10%) it was the main form of N (75%) transported in the other runoff types and in streamflow. Subsurface runoff contributed the major proportion of stream discharge (63%), and NO_3–N (69%), particulate N (44%) and TN (65%) loading of the stream. The results are discussed in terms of non-point pollution of surface waters by NO_3–N.

1. Introduction

The transport of nitrogen (N) in runoff waters from agricultural watersheds has caused increasing concern in recent years because of its role in the accelerated eutrophication of natural waters (Makenthun, 1965; Vollenweider, 1968; Stanford *et al.*, 1970; Menzel, 1978). As nitrate (NO_3–N) is highly mobile in soil, fertilizer or native soil N in excess of crop needs is available for leaching and can move into ground water and subsurface stream flow (Power, 1970; Pratt *et al.*, 1972; Schuman *et al.*, 1975). Consequently, considerable interest has been directed towards the NO_3–N concentration of surface waters, as accumulations ($>$ 10 mg l^{-1} NO_3–N) can be hazardous to human health (Gruener and Schuval, 1970).

Several studies have reported that variations in the concentration of total N (TN) and NO_3–N can occur with fluctuations in the rate of dischaerge of surface (Kissel *et al.*, 1976), accelerated subsurface (tile drain discharge) (Baker *et al.*, 1975), and subsurface runoff (Minshall *et al.*, 1969) and of stream flow (Muir *et al.*, 1973; McColl *et al.*, 1975). As a result of these fluctuations in N concentration, it is likely that the estimates of the loading of N forms in the three runoff types and stream flow will vary with sampling frequency. In a recent study Sharpley *et al.* (1976) observed that with infrequent sampling, large errors in estimates of the amounts of P discharged in the runoff types and stream flow could occur.

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Although many studies have investigated the amounts of N forms transported in the runoff types and stream flow (Jackson *et al.* 1973; Burwell *et al.*, 1974; Baker *et al.*, 1975), few have investigated these losses in the runoff types and stream flow in the same watershed (Burwell *et al.*, 1976). In the present study, the ability to measure the amounts of N transported in each runoff type in a watershed where input from the three runoff types could be quantified, presented an ideal situation to investigate the relative significance of the runoff types in the discharge and N loading of a stream.

This paper reports on an investigation of (i) the relationships between flow and concentration of N forms, (ii) the sampling frequency required to reliably estimate the loading of N forms, (iii) the amounts of N forms transported in surface, accelerated subsurface, and subsurface runoff and stream flow, and (iv) the relative significance of the three runoff types to stream flow and N discharge from a watershed under pasture.

2. Materials and Methods

The watershed under study, located adjacent to Massey University, Palmerston North, New Zealand, has been described previously by Sharpley *et* al. (1976). Stream flow is monitored at two sites in the watershed isolating a subwatershed of 20 ha, within which surface and accelerated subsurface runoff are continuously monitored by the installations detailed earlier (Sharpley *et al.*, 1976). The amounts of water discharged in subsurface runoff were estimated from analysis of the stream flow hydrograph, as represented by Wisler and Brater (1949). Tokamoru silt loam is the only soil type in the pasture watershed, which is intermittently grazed by dairy cattle, at an approximate rate of 25 cattle ha^{-1}. Urea was applied annually (60 kg N ha^{-1}) to the drained area of the subcatchment (14 ha) in early fall (April).

Surface and accelerated subsurface runoff and stream flow samples were collected at intervals varying from 2 to 3 min, as described by Sharpley *et al.* (1976). Analysis of N forms was carried out using a Technicon Auto-Analysis system. Nitrate–N was determined on a filtered sample (< 0.45 μm) by the automated Gresiss–Ilsovay method following reduction by cadmium (Hendrikson and Selmer–Olsen, 1970). Total Kjeldahl (TKN) was determined by the automated Kjeldahl digestion of an unfiltered sample (Terry, 1966), and is subsequently referred to as particulate N. Total N was calculated as the sum of NO_3–N and TKN.

3. Results and Discussion

3.1. Interrelationships between flow and concentration of N forms

3.1.1. *Runoff Types*

The NO_3–N concentration of surface runoff during a typical event is presented in Figure 1. A slight decrease in concentration (0.6 to 0.2 mg l^{-1}, Figure 1) was apparent during the event, reflecting a dilution of the NO_3–N source in the soil surface during

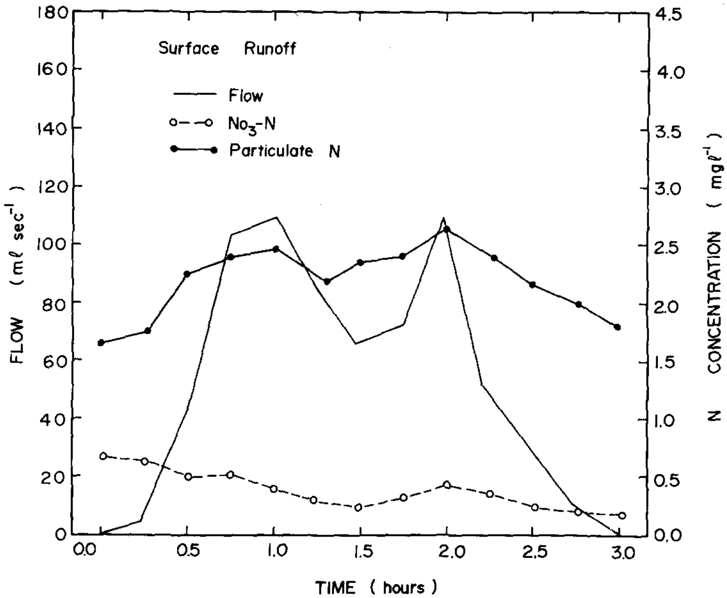

Fig. 1. Flow and NO_3–N and particulate N concentration during a typical surface-runoff event.

runoff (Burwell *et al.*, 1975a). In contrast, the concentration of particulate N increased as flow increased (Figure 1). In the case of accelerated subsurface runoff, the concentration of NO_3–N decreased rapidly with an increase in flow, with the minimum value (1.5 mg l^{-1}) coinciding with peak flow, in the typical event presented (Figure 2). As

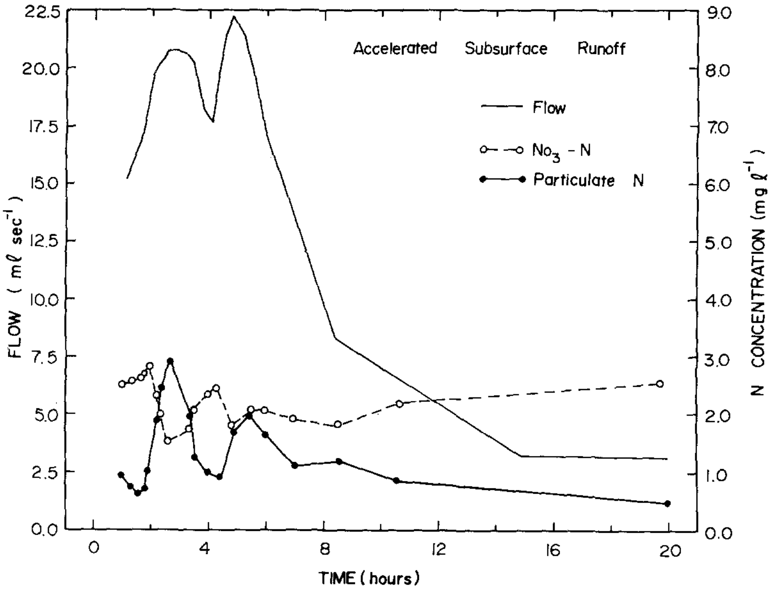

Fig. 2. Flow and NO_3–N and particulate N concentration during a typical accelerated subsurface-runoff event.

flow decreased, NO_3–N concentration gradually increased to its initial value (2.5 mg l^{-1}). As was the case for surface runoff, particulate N concentration increased with an initial increase in accelerated subsurface flow (Figure 2), attaining a maximum value at peak flow. A secondary increase in tile discharge was associated with a slight increase in particulate N concentration and decrease in NO_3–N concentration (Figure 2). The concentration of NO_3–N and particulate N attained constant values (3.0 and 0.5 mg l^{-1}, respectively) during prolonged periods of subsurface flow (Figure 3). These values were similar to those observed in accelerated subsurface runoff during flow recession.

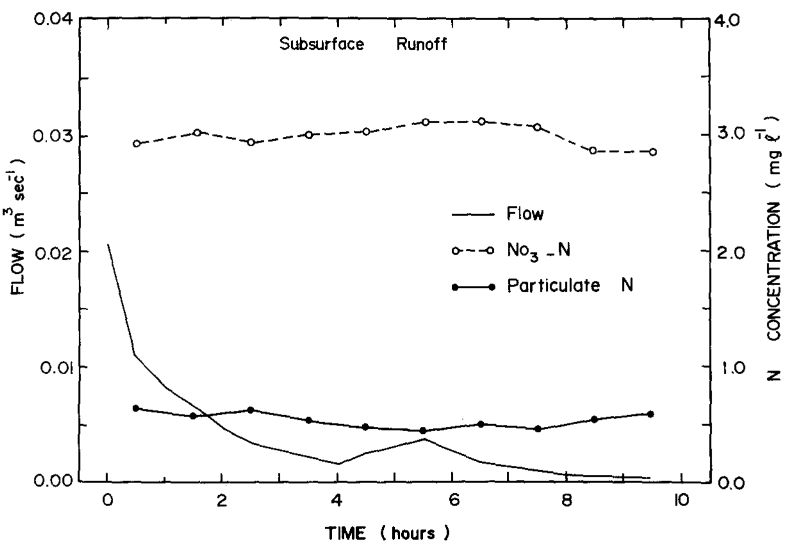

Fig. 3. Flow and NO_3–N and particulate N concentration during a typical subsurface-runoff event.

3.1.2. *Stream Flow*

The concentration of NO_3–N decreased gradually with an increase in stream flow reaching a minimum value at peak flow (Figure 4). With flow recession, NO_3–N concentration gradually increased reaching a concentration greater than that at the beginning of the event. In contrast, the concentration of particulate N increased with an increase in flow with maximum values obtained at peak flow. A secondary increase in stream flow was associated with a decrease in NO_3–N concentration and a slight increase in particulate N concentration (Figure 4). The differing concentration-flow trends for NO_3–N and TN during the initial stages of stream flow increase are a consequence of an increased contribution of particulate N to stream flow from surface runoff during this period. As the contribution of subsurface flow to stream flow increases, NO_3–N constitutes the major form of N in stream flow.

Similar concentration-flow relationships were observed for all runoff types for the other events sampled in detail, although differences in NO_3–N and particulate N concentration between consecutive events were apparent. The intensity and duration

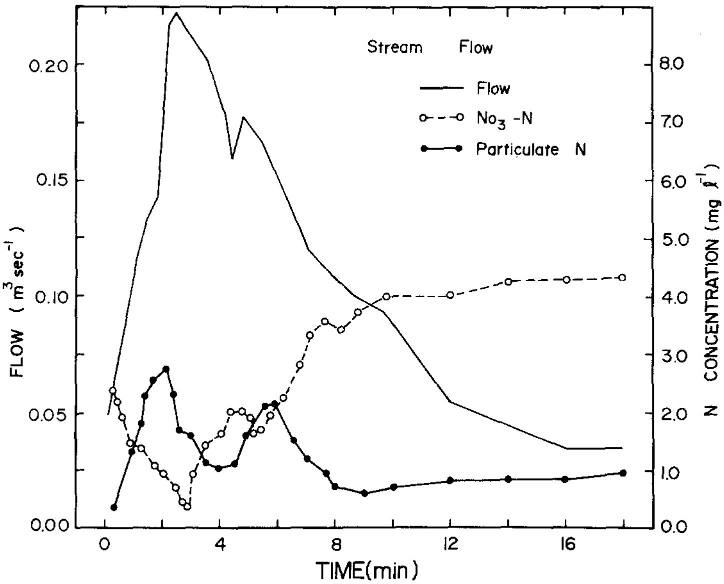

Fig. 4. Flow and NO_3–N and particulate N concentration during a typical stream-flow event.

TABLE I

Annual mean concentrations of N forms in the runoff types and stream flow

N Form	Mean Concentration			
	Surface runoff	Accelerated subsurface runoff	Subsurface runoff	Stream flow
	mg l^{-1}			
		1975		
NO_3–N	0.4	8.5	5.0	5.2
Particulate N	4.0	1.7	1.0	1.5
TN	4.4	10.2	6.0	6.7
		1976		
NO_3–N	0.2	4.0	3.8	3.2
Particulate N	2.6	2.3	1.1	1.5
TN	2.8	6.2	4.9	4.7
		1977		
NO_3–N	0.3	7.4	5.7	5.4
Particulate N	2.7	2.1	1.3	1.8
TP	3.1	9.6	7.0	7.2
		3-yr average		
NO_3–N	0.3	6.6	4.8	4.6
Particulate N	3.1	2.0	1.1	1.6
TN	3.4	8.7	5.9	6.2

of storms and their effect on soil moisture conditions prior to runoff and dilution of the pool of soil N susceptible to loss in runoff, can result in concentration differences between events. In addition, an increasing time interval between events will result in an increasing mineralization of organic N and may allow a larger pool of NO_3–N to accumulate in the soil profile. Sharpley (1980) observed that an increase in the soluble P concentration of surface runoff, with increasing intervals between storms, was directly related to the mineralization potential of organic P in the surface soil.

The mean concentrations of NO_3–N, particulate N, and TN in the runoff types and stream flow for the 3 yr study, calculated from annual loadings and discharge, are presented in Table I. It is apparent that for the 3 yr of study, NO_3–N and particulate N concentrations were only 4.6 and 1.6 mg l^{-1}, respectively, event though urea (60 kg N ha^{-1}) was applied annually to 2/3 of the watershed. Thus, the loss of N from

TABLE II

Annual amounts of water discharged and N forms transported in surface and accelerated subsurface runoff, and stream flow obtained from field measurements, and in subsurface runoff, obtained from hydrograph analysis

Parameter	Amount transported in			
	Surface runoff	Accelerated subsurface runoff	Subsurface runoff	Stream flow
	kg ha^{-1} yr^{-1}			
		1975		
Discharge[a]	1330	1250	2020	3010
NO_3–N	0.5	10.6	10.1	15.6
Particulate N	5.3	2.1	1.9	4.6
TN	5.8	12.7	12.0	20.2
		1976		
Discharge[a]	2850	2300	3680	6030
NO_3–N	0.6	9.0	14.0	19.4
Particulate	7.3	5.2	3.9	9.1
TN	7.9	14.3	17.9	28.5
		1977		
Discharge[a]	1540	1150	1900	2820
NO_3–N	0.5	8.5	10.8	15.3
Particulate N	4.2	2.5	2.5	5.2
TN	4.7	11.2	13.3	21.4
		3-yr average		
Discharge[a]	1910	1570	2530	3950
NO_3–N	0.5	9.4	11.6	16.8
Particulate N	5.6	3.3	2.8	6.3
TN	6.1	12.7	14.4	23.4

[a] Discharge expressed as m^3 ha^{-1} yr^{-1}.

the watershed studied presents little concern from a water quality standpoint. Because only slight changes in concentration with flow for the runoff types and stream were obtained, one sample taken during each event would, therefore, be sufficient to obtain reasonable estimates of N loadings, as long as flow was monitored intensively (Frere, 1971; Burwell *et al.*, 1975a; Stevens and Smith, 1978).

3.2. Amounts of N Forms Transported

3.2.1. *Runoff Types*

The annual amounts of water discharged and N forms transported in surface runoff from the plots for the 3 yr of study are presented in Table II. Because the amounts transported in the three runoff types are presented on a per hectare basis, when combined they do not equal those transported in stream flow. It was apparent that particulate N accounted for the major proportion of the TN transported in surface runoff (92, 93, and 89% for 1975, 1976, and 1977, respectively). This is consistent with work reported by Burwell *et al.* (1975b), who observed that 96% of the TN transported (4.1 kg ha^{-1} yr^{-1}) in surface runoff from an unfertilized soil under hay in Minnesota was attached to sediment. An even greater disparity between the transport of NO_3–N (0.1 kg ha^{-1} yr^{-1}) and TN (5.0 kg ha^{-1} yr^{-1}) in surface runoff was measured by Timmons *et al.* (1973) from a fallow soil in Minnesota.

The amount of NO_3–N transported in accelerated subsurface runoff was appreciably greater than that transported in surface runoff for the 3 yr of study (Table II) and constituted the major proportion of the TN discharged (83, 69, and 76% in 1975, 1976, and 1977, respectively). The amounts of N forms transported in subsurface runoff were similar to those transported in tile discharge (Table II), with NO_3–N accounting for the major proportion of the TN transported (84, 78, and 81% in 1975, 1976, and 1977, respectively).

The differences between the transport of N forms in surface and accelerated subsurface runoff can be attributed to the fact that because NO_3–N is a non-specifically sorbed anion, it is able to move rapidly through the soil profile in drainage water (Harmsen and Kolenbrander, 1965), away from the zone of removal in surface runoff. In addition, the markedly greater transport of particulate N in surface runoff than in tile discharge, may be attributed to the increased transport of particulate material in the former runoff type (Sharpley and Syers, 1979).

3.2.2. *Stream Flow*

In July 1975, 100 dairy cattle grazed the undrained area (6 ha) of the subcatchment at a stocking rate of 25 cattle ha^{-1} for 10 days. During this period a slight increase in the concentration of particulate N was observed, whereas NO_3–N concentration remained virtually constant. In addition, the concentration of NO_3–N and particulate N entering the subcatchment remained constant and surface and accelerated subsurface runoff did not occur during the period of grazing. Consequently, the observed increase in particulate N can be attributed to the movement of cattle in the stream channel, stirring up bottom sediments and depositing excreta in the stream. The data presented confirm previous suggestions that increased nutrient concentrations of stream base flow can result from grazing cattle (Minshall *et al.*, 1969; Lusby *et al.*, 1971).

Stream discharge in 1976 (6030 m^3 ha^{-1} yr^{-1}) was approximately twice that in 1975 and 1977 (3010 and 2820 m^3 ha^{-1} yr^{-1}, respectively), however, only a 25% increase in NO_3–N discharge was observed during the high-flow year. It appears, therefore, that the pool of NO_3–N susceptible to loss from the soil was of similar size for each year of the study. In contrast, a similar increase in particulate N transport and stream discharge (2-fold increase in 1976 compared to 1975 and 1977, Table II), indicates the dependence of this N form on increased soil material transport with higher flows (10-fold increase in sediment transport in 1976 compared to 1975 and 1977; Sharpley and Syers, 1979).

A greater amount of NO_3–N and TN was transported in stream flow from the subwatershed in the present study (16.8 and 23.4 kg ha^{-1} yr^{-1}, Table II) than from pasture watersheds of similar management in South Dakota (0.4 and 1.1 kg ha^{-1} yr^{-1}, respectively; Harms *et al.*, 1974) and North Carolina (2.4 and 3.3 kg ha^{-1} yr^{-1}, respectively, Kilmer *et al.*, 1974). The increase transport of NO_3–N and TN from the present watershed compared to overseas watersheds of similar land use and management indicates the importance of N fixation by clover and the effect of grazing animals on the losses of NO_3–N from watersheds in New Zealand.

3.3. Relative Significance of the Runoff Types

The relative contribution of surface, accelerated subsurface, and subsurface runoff to the flow and N loading of the stream draining the subwatershed, calculated from annual discharge and loadings, is presented in Table III. The amounts of water discharged and N forms transported in surface and accelerated subsurface runoff were estimated from field data, whereas those in subsurface runoff were obtained from hydrograph analysis (Sharpley and Syers, 1979). As a result, the sum of the contribution of the runoff types to stream flow and N discharge presented in Table III, does not necessarily equal the total amount transported in stream flow. It is apparent from the data presented in Table III that although there was an approximately twofold greater stream discharge in 1976 compared to the other 2 yr of study (Table II), remarkably similar proportions of the annual discharge and N loadings of the stream were contributed by the runoff types for each year of study.

Subsurface runoff contributed the major proportion of the annual discharge and loading of N forms in the stream, with surface runoff contributing only negligible proportions (Table III). This is in agreement with several studies which have shown that the major proportion of stream flow is contributed by subsurface runoff. Minshall *et al.* (1969) observed that over a period of 25 years, subsurface runoff accounted for 60% of the annual flow in the Platte River, Wisconsin, whereas Burwell *et al.* (1976) reported that subsurface runoff contributed 88% of the annual stream flow in a watershed under pasture in Iowa. Similar trends for the N loading of stream flow have

TABLE III

Relative contribution of surface, accelerated subsurface, and subsurface runoff to the annual discharge and N loading of the stream in the subwatershed

Parameter	% Contribution of runoff inputs		
	Surface	Accelerated subsurface	Subsurface
		1975	
Discharge	9	28	67
NO_3–N	1	46	65
Particulate N	26	32	42
TN	6	42	69
		1976	
Discharge	9	26	61
NO_3–N	1	32	72
Particulate N	18	40	42
TN	6	34	63
		1977	
Discharge	11	28	61
NO_3–N	1	39	70
Particulate N	18	33	69
TN	4	37	62
		3-yr average	
Discharge	10	27	63
NO_3–N	1	39	69
Particulate N	21	35	44
TN	5	38	65

also been observed by Burwell *et al.* (1974), who found that 78% of the annual NO_3–N loading of a stream in Iowa was contributed by subsurface runoff and by Jackson *et al.* (1973) who reported that subsurface runoff contributed 99% of the NO_3–N transported in total runoff from a watershed in Georgia.

The data presented indicate that because NO_3–N concentration changed only slightly during stream flow and concentrations were not high enough to cause a water quality problem, one sample for each runoff event would provide an adequate estimate of N loading for the watershed studied. This would minimize lengthy and expensive analytical work, allowing water quality data to be obtained from a larger number of watersheds. Because of the major contribution of subsurface runoff to NO_3–N transport in stream flow, the importance of minimizing this loss is indicated, in effecting a reduction in the non-point pollution hazard of N. This may be partially attained by the application of N fertilizer at rates that do not exceed crop requirements. Although deep percolation did not contribute to stream flow in the watershed studied, in larger watersheds increasing concentrations of NO_3–N in groundwater may take years to reverse due to its slow movement.

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